

Analysis of Loads and Wind Energy Potential for Remote Power Stations in Alaska

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ABSTRACT

This report addresses the potential of utilizing wind energy in remote communities of Alaska. About 175 Alaskan villages are located beyond the reach of the central power grids serving the major urban areas. Instead, they are powered by diesel mini-grids. Along with the high cost of fuel delivery and bulk fuel storage tanks, these communities are exposed to environmental hazards associated with diesel generators, including the potential for fuel spills and the emission of greenhouse gases and particulates.

To address these issues, Alaska energy representatives are looking to renewable energy technologies. This report evaluates the village electric usage patterns, wind energy resource potential, and wind-diesel hybrid power options for three remote communities in Alaska. Conclusions are made to generalize the results for use in other arctic villages.

1. INTRODUCTION

About a quarter of Alaska's population of 640,000 live in isolated villages scattered across the state. More than 118 independent utilities provide electricity to this geographically, economically, and culturally diverse range of communities (1). The Alaska Village Electric Cooperative (AVEC) operates 47 power stations serving 52 remote villages ranging in size from 100 to 1,100 residents. Much of the data used in this analysis was provided by AVEC and this paper will focus on those villages.

Due to the rugged terrain and lack of a roadway system, supplying rural Alaskan communities with electricity is a challenge. Villages are powered by diesel mini-grids of up to 3 MW in capacity. The delivery of fuel is limited to 1-4

shipments by barge per year and is dependent upon favorable weather conditions. A 9 to 13 month supply of fuel must be stored on site in tank farms, which may be subject to leaks and spills. Many of the plant complexes and storage tanks are aging and in need of major upgrades.

As the least-cost small-scale renewable energy technology currently available, wind energy is a serious option in reducing the use of diesel and the exposure to fuel price volatility. This report will focus on the potential of integrating wind energy into existing diesel power stations in three Alaskan communities: Chevak, Scammon Bay, and Selawik. Table 1 summarizes characteristics of these villages, based on data from 2002.

Table 1: 2002 Village Statistics

	Chevak	Scammon Bay	Selawik
Population	850	490	780
Electric Use (kWh/year)	2,173,400	1,032,800	2,520,500
Average Load	300 kW	140 kW	280 kW
Peak Load	600 kW	440 kW	340 kW
Yearly Diesel Consumption	160,230 gal	79,600 gal	189,100 gal
Total Diesel Capacity	1163 kW	807 kW	1221 kW
Fuel Storage Capacity (gal)	164,000	97,000	165,000

2. ANALYSIS OF VILLAGE ENERGY USE

Data obtained from AVEC for the power systems that it operates was analyzed to determine energy use trends for remote communities. Figure 1 shows the approximate breakdown of electric use in the AVEC service area.

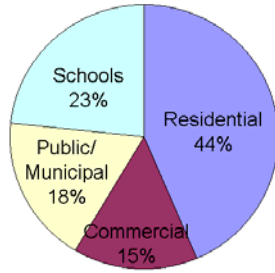


Fig. 1: Village Electric Use by Sector

2.1 Primary Electricity Users

The residential sector is the largest consumer of electricity, followed by the school and public sectors. Public facilities include a water treatment plant, post office, airport, and city offices. The residential load is driven by the number of homes in a community and their socio-economic condition. Typically, the two primary non-residential customers in a village are the school and the public water treatment facility.

As the single largest electric user in a village, the schools have a great impact on the total village electric load profile. Villages usually have one K-12 school building that serves up to 400 students. Major electric loads within the school include air handling units, lighting, water pumps for a hot water radiator system, and kitchen appliances. For safety reasons, ranges and ovens in the cafeteria may use electricity rather than propane. Space heat is usually provided by oil-fired furnaces or by heat recovered from the power plant cooling system.

Figure 2 shows the average load profile for a typical school, based on a survey of eight schools. The energy use of the schools in Chevak, Selawik and Scammon Bay are shown for comparison. The loads have been normalized to the population so that the differences in the profiles can be observed without the distortion of community size.

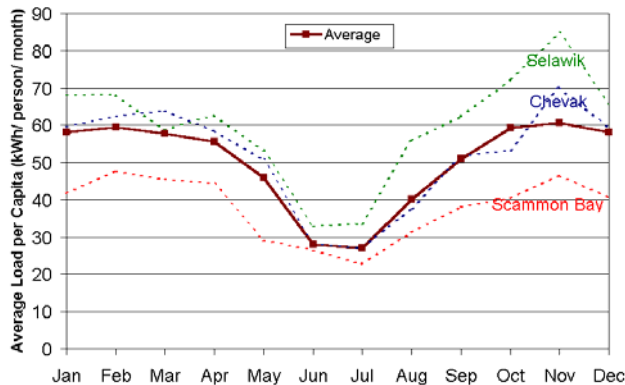


Fig. 2: Electric Use of K-12 Schools

The factors influencing the electric consumption of a public water system include the size of the population served, the level of treatment of the water and wastewater, the method of distribution, and the climate. Village public water systems can generally be split into two levels.

Level I public water systems provide piped water and sewer to all city buildings and most homes. These systems often have aboveground water mains, which need to be protected from freezing. Options include heating the water mains with electric heat trace, using a boiler to heat an anti-freeze loop, or continuously pumping the water through a closed-loop distribution system.

In Level II public water systems, water is pumped from a well or surface source, treated, and stored in an insulated tank. The water is supplied to a central washeteria where residents can collect water, bathe, and do laundry. Electric loads at these water treatment/washeteria facilities include pumps, washing machines and dryers, lights, and sometimes an electric sauna. These basic systems do not treat wastewater; instead, each resident collects their wastewater in five-gallon “honey buckets” and hauls them to a sewage lagoon to be dumped.

Figure 3 shows the average monthly electric consumption of the basic and the piped public water systems, based on a survey of utility bills from 10 villages. Again, the loads are normalized by population.

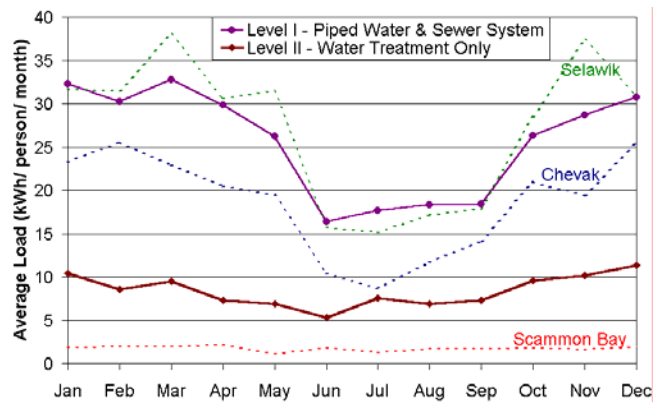


Fig. 3: Average Electric Use of Public Water Systems

The electric consumption of public water systems can vary drastically from village to village. Most villages, such as Scammon Bay, begin with a basic Level II system and gradually move towards a Level I system, such as that in Selawik, as funding is available.

2.1 Village Electric Load Profiles

The seasonal variances of the schools and public water facilities are reflected in the total village load profile. AVEC monitored the instantaneous electric load in the three villages every 15 minutes from 1999 to 2003. The seasonal load profiles based on this information are shown in Figure 4.

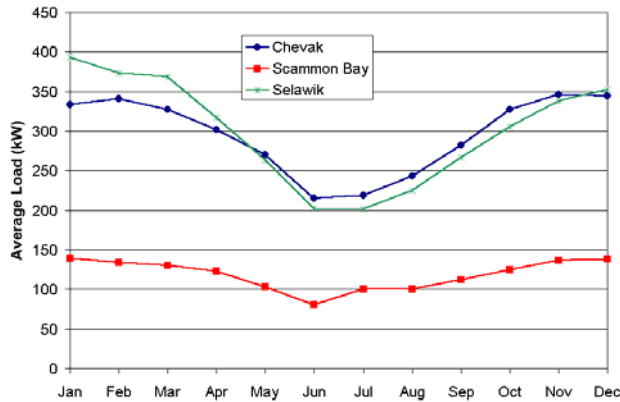


Fig. 4: Seasonal Load Profiles

The differences in the seasonal load profile between villages depends on the number and types of facilities in the community as well as the climate. Although Chevak and Scammon Bay are in the same geographic climate region, Chevak has a much greater difference between summer and winter loads. This is most likely due to the seasonal variation in Chevak’s public water system compared to that of Scammon Bay.

Figure 5 compares summer and winter daily load profiles for the three communities. While the magnitude of the load fluctuates from summer to winter, the shape of the profile changes little. It is also important to note that the shape of the profile is similar between villages of different sizes.

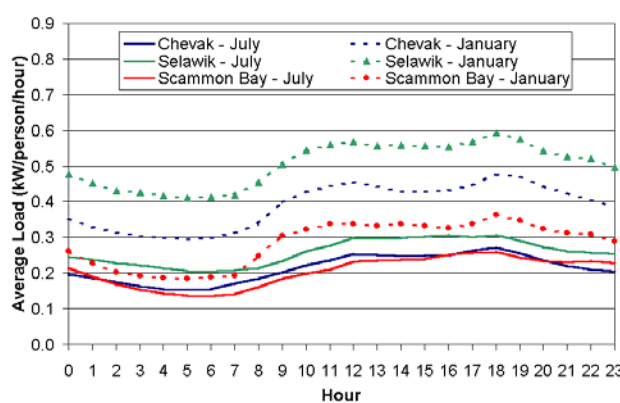


Fig. 5: Summer and Winter Daily Load Profiles

When evaluating power system options, the electric load data for these villages were scaled up to account for an

expected growth of 3% each year for the next 5 years. This does not affect the shape of the seasonal and daily profiles.

3. WIND RESOURCE

Of the 175 remote villages in Alaska, it is estimated that 90 are located in potentially windy regions (3). The wind resource map in Figure 6 shows that wind speeds of up to class 7 occur along the Alaskan coastal and islands areas and over the mountainous areas in the interior (4).

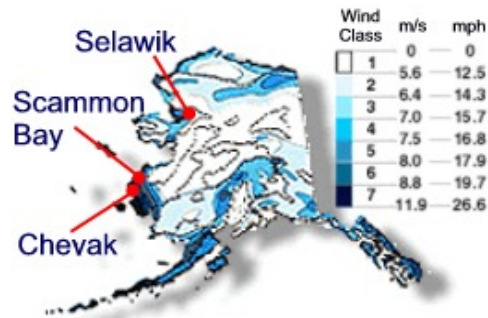


Fig. 6: Alaska Wind Resource Map

Hourly wind speed data from 1999 were obtained from local airports in or near each village. This data was scaled up or down based on the long-term (1994-2002) average monthly wind speeds at each location. They were then scaled up based on the standard power law exponent of 0.143 to account for the increased wind speeds at a wind turbine hub height of 25 meters. The adjusted seasonal wind profiles for each village are shown in Figure 7.

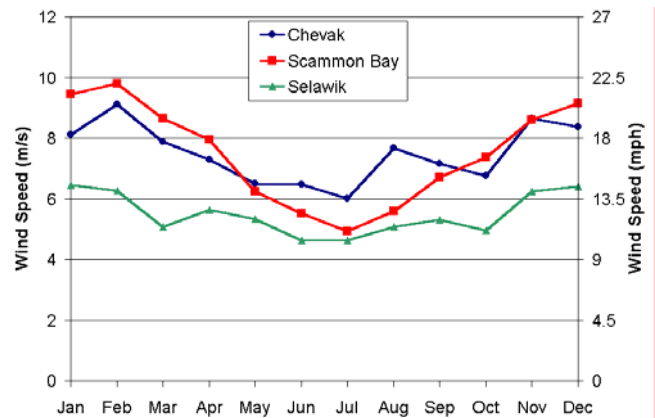


Fig. 7: Seasonal Wind Profiles

The wind resource tends to be greater in the winter than the summer, which corresponds to the seasonal electric usage patterns of the villages described earlier.

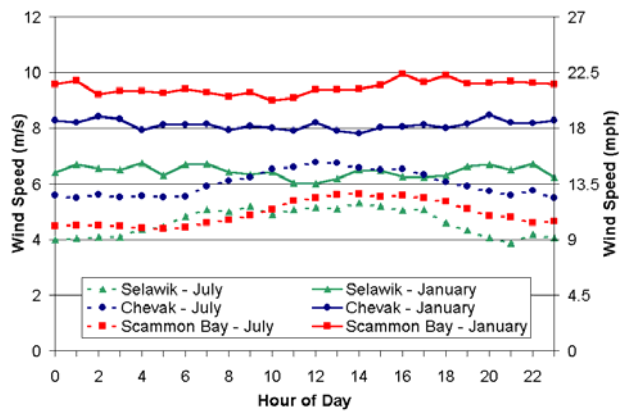


Fig. 8: Average Winter and Summer Diurnal Wind Profiles

The daily wind speed profiles shown in Figure 8 indicate that wind speeds are fairly constant throughout the day, which would allow wind turbines to provide a fairly steady output of electricity.

4. WIND-DIESEL HYBRID SYSTEMS

The most promising application of renewable energy in Alaska is adding wind turbines to diesel power plants that are being upgraded to make a hybrid wind-diesel system. The wind turbines are connected directly to the grid and operate in parallel with the diesel generators, adding wind-generated electricity to the grid when available.

Various levels (penetrations) of wind energy can be added to the system. In low penetration systems, the wind turbine(s) are simply an additional generation source, requiring a trivial amount of controls. In medium-penetration systems, the average wind turbine output is up to 50% of the average electric load, allowing some diesel generators to be shut off or allowing smaller diesels to be used. Additional controls are required to ensure an adequate power balance and to maintain system voltage and frequency. High-penetration systems allow all the diesels to be shut off for long periods of time, but require more sophisticated controls and system integration (5).

Demonstration wind-diesel hybrid systems are currently operating in the Alaskan villages of Wales, Kotzebue, and St. Paul. The latest wind-diesel system went online in Selawik in the Fall of 2003 (data collected prior to the wind installation is used in this analysis). Although much experience has been gained from these systems, the wind-diesel industry in Alaska is still fairly new (6).

4.1 Wind Turbines

Cold weather climates such as that in Alaska impose significant restrictions on the choice of wind turbine.

Turbine design considerations include the potential icing of sensors and blades, increased fatigue on components, and changes in material properties at lower temperatures (particularly with the gearbox oil and rubber seals). The installation and maintenance of wind turbines is also affected by extreme weather conditions. Deep snowfall can limit access to wind turbines, and sub-zero temperatures create additional safety issues. The physical size of the turbine components is restricted to their ability to fit on a plane for shipment and the limited installation infrastructure in remote areas.

Only a few manufacturers of mid-sized wind turbines have a presence in the U.S. and Canada. The wind turbines most commonly installed in Alaska are the 65kW Atlantic Orient AOC15/50 and the 100kW Northern Power NW100/19. Therefore, this analysis focuses on the use of these machines. The power curves were adjusted to account for the higher air density in cold climates.

4.2 Storage

An additional design consideration for hybrid systems is the level and type of energy storage device. The amount of storage influences the system's ability to cover short-term fluctuations in wind energy and/or the village load. The addition of energy storage into a high-penetration wind-diesel system can increase the fuel savings and reduce the diesel generator operating hours and number of starts. These factors affect the wear on the diesel machines and resulting maintenance and overhaul costs. However, the storage equipment is expensive to ship, install, and maintain, and their useful lifetime is limited to 5-15 years.

In low penetration systems, storage is not required since the wind does not provide enough power to allow the diesels to be shut off. Storage is also not required in medium and high-penetration systems if an adequate dump load and synchronous condenser are provided to maintain voltage and frequency stability. This preliminary analysis investigates the potential of low to high penetration systems with no storage. The costs and benefits of adding battery storage systems will be considered at a later time.

4.3 Expected Performance of Hybrid Systems

To compare the design options of hybrid power systems, the computer simulation model HOMER, developed by the National Renewable Energy Lab, was used (7).

The primary performance indicator by which the options will be ranked is the amount of diesel fuel savings of the wind-diesel system relative to the existing system. Figure 9 shows the annual fuel savings that would result from the installation of up to 30 AOC 15/50 wind turbines in each

village, and Figure 10 shows the potential savings with the larger NW100/19 machines. Fuel savings are based on the expected 2009 annual fuel consumption of 227,300 gallons in Chevak; 88,400 gallons in Scammon Bay; and 222,800 gallons in Selawik.

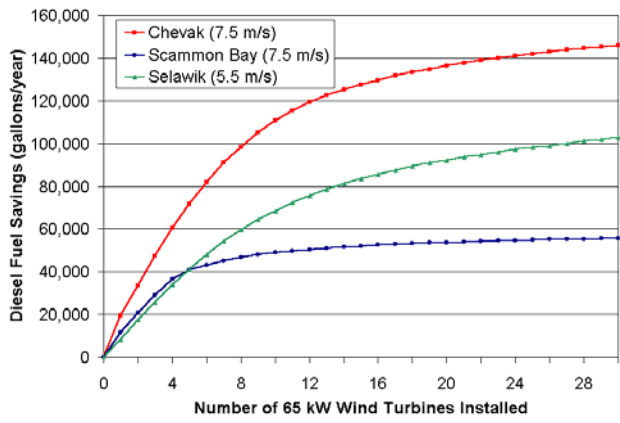


Fig. 9: Impact of 65kW Wind Turbines on Fuel Savings

Factors affecting fuel savings include the individual village electric needs and the local wind resource. Although Chevak and Scammon Bay have a nearly identical wind resource, Scammon Bay gains less from wind turbines because the village demand is not large enough to use most of the wind electricity produced. Similarly, the local wind resource impacts the level of fuel savings. Although Chevak and Selawik are of similar size and have nearly identical electric load profiles, Chevak would receive more immediate benefit from the installation of wind turbines than Selawik due to the superior wind resource.

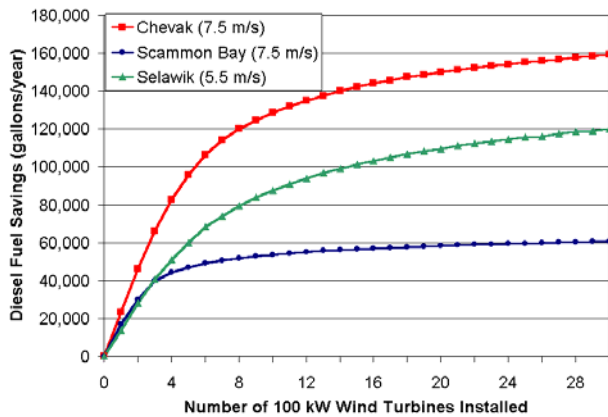


Fig. 10: Impact of 100kW Wind Turbines on Fuel Savings

The figures clearly show that as the amount of wind generation increases, the fuel savings resulting from the next incremental installed turbine decreases, due to the fact that

some of the potential wind energy generated cannot be used. In some cases a clear inflection point can be seen in the curve, indicating a local economic optimum of potential installation.

5. THERMAL ENERGY

An additional benefit of a high-penetration wind-diesel system is that the excess wind energy generated could supply power to an optional load. Alaska's climate supports this concept of higher-penetration systems because any excess energy can be used year-round for heating. Currently, some villages use heat recovered from the diesel power plant to provide space heating or hot water. This recovered heat use must be considered in the installation of any alternative generation source that may reduce the use of the diesel engine.

Chevak will be used to illustrate the potential of excess energy to meet heating loads in the village. According to plant personnel, the Chevak water treatment facility currently obtains its heat from an oil furnace that consumes 5,000 gallons of #1 oil in the winter months and 2,000 gallons in the summer months, which translates to approximately 120 MWh and 50 MWh per month, respectively, in electrical heating needs. The fuel cost is \$2.40 per gallon, excluding shipping costs. Figure 11 shows the amount of excess wind energy that would be available to supply this heating load each month if various numbers of 65kW wind turbines were installed in Chevak.

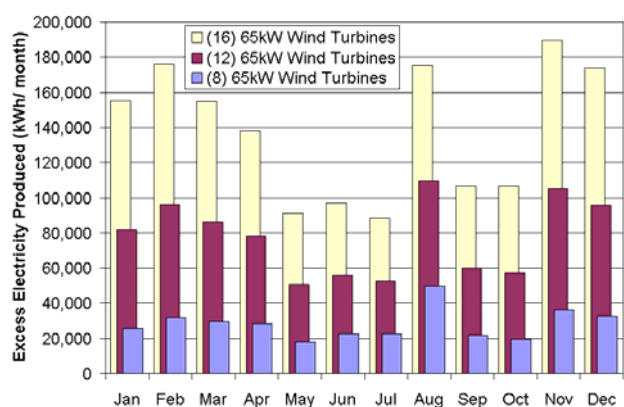


Fig. 11: Excess Electricity Produced in Chevak

6. ECONOMICS

The installation or upgrade of any power system in Alaska is often dependent on government funding sources and the availability of low-interest loans. State and federal funding, as well as funding from native or private corporations is available for projects in Alaska.

Due to the unique conditions of Alaska, particular costs are incurred during the installation of a wind energy system. For example, the wind turbine foundations are designed to have minimal impact on the frozen tundra, and often the installation must take place during the winter to ensure that the frozen ground will support the weight of the cranes, pile drivers, and fork lifts. Based on manufacturer quotes and data from previous installations, Table 2 summarizes the costs of equipping a diesel power station with wind turbines. The wind turbine cost includes installation and shipment.

Table 2: Installed Cost of System Components

	65kW Turbine	100kW Turbine
Wind turbine, each	\$165,000	\$340,000
Foundation, each	\$100,000	\$100,000
Annual O&M	\$3,000	\$4,500
Balance of System	\$150,000 to \$250,000	

The balance of system cost, which includes diesel controls, supervisory controls, a dump load, line extensions and facility upgrades, can vary depending on the level of wind penetration. Depending on the complexity of the system, the total cost for a retrofit wind-diesel system is up to \$5,000 per kW of rated wind power. These costs are expected to decrease as more experience is gained with the installation of wind turbines in arctic conditions.

The economic benefits of a wind-diesel system result from fuel savings, a potential reduction in diesel O&M and overhaul costs, and the potential value of excess wind energy generated. The use of wind energy also delays the need for additional fuel storage tanks. Approximate values for these parameters are shown in Table 3.

Table 3. Estimated Cost of Diesel Components

Diesel Fuel Cost	\$1.35/gal (\$0.36/liter)
Diesel O&M	\$5.00/operating hour
Diesel Overhaul	\$30,000 per 10,000 hours
Diesel Storage Tank	\$2.50 per gallon of capacity
Storage Tank O&M	\$0.40 per gallon of capacity

The uncertainty of funding sources makes it difficult to accurately calculate the life-cycle cost of a hybrid system; however, a simple example is given for the case of installing eight 65kW wind turbines in Chevak. The cost with no subsidies would be about \$2,350,000. The wind turbines would generate 1,540 MWh of useable energy per year (plus an excess of 340 MWh) and would save \$135,000 in diesel fuel per year (100,000 gallons). Based on a loan interest rate of 6% and a general inflation rate of 3%, the levelized cost of energy is \$0.13 per kWh.

The current cost of generating electricity is about \$0.09/kWh, excluding the maintenance costs of the diesel generators and tank farms. The average residential electric

rate, including generation and distribution, is \$0.40/kWh. Through the Power Cost Equalization program, the state subsidizes the first 500 kWh per month of residential energy costs in most villages to a rate of about \$0.20/kWh.

7. CONCLUSIONS

This paper describes a method to investigate the use of wind generation technology to reduce the dependence on diesel fuel to supply the power needs of rural communities. Based on the analysis of electrical use in a number of rural communities, this paper provides a method to estimate the electrical loads; one of the key pieces of information required to conduct any detailed analysis.

Although a handful of newly installed hybrid wind-diesel systems currently exist in several Alaskan villages, a comprehensive study of the potential in other villages has not been done. This report is the beginning of that comprehensive effort.

8. ACKNOWLEDGMENTS

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